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EVOLUTION OF THOUGHT ON FLUVIAL GEOMORPHOLOGY THOUGHT IN THE UNITED STATES

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Analyzes the formulation of the major concepts and ideas in the field of fluvial geomorphology in the United States. The discussion is divided into four sections: early history, William Morris Davis, Quantitative Revolution, and present era. Abstracts of major articles relating to the four periods are included as an Appendix.

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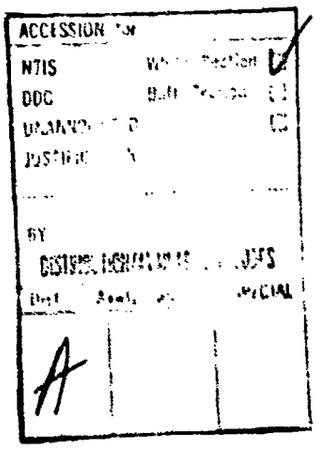

INTRODUCTION

There have been many attempts to trace the development of geomorphic thought in the United States, however, most of these are detailed and often difficult for the typical undergraduate student to comprehend.[1] Further, as is the case in many other fields of study, geomorphology is subdivided into several sub-fields. Among these are fluvial, glacial, eolian and climatic geomorphology. The purpose of this report is to synthesize the information contained in significant articles relating concepts and ideas in fluvial geomorphology. The discussion covers four periods: the early history, the William Morris Davis era, the quantitative revolution, and the present day. The section relating to the present day serves as a summary for the paper.

Terms used in this paper are those which should be common to the reader of articles on geomorphology. The appendix contains abstracts of major articles relating to the four named periods.

EARLY HISTORY

Many of the concepts in fluvial geomorphology in the United States can be traced to European origins; however, "Classical" American geomorphology as expressed by W.M. Davis has its roots in

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[1] See: Chorley, R.J., A.J. Dunn, and R.P. Beckinsale. The History of the Study of Landforms, Vol. I. (London: Methuen & Co., Ltd., 1964); Chorley, R.J., R.P. Beckinsale, and A.J. Dunn. The History of the Study of Landforms, Vol. II. (London: Methuen & Co., Ltd., 1973); and Dury, George H. Perspectives on Geomorphic Processes. Association of American Geographers Resource Paper No.3 (Washington, D.C.: AAG, 1969).

the Surveys of the Western United States conducted by the U.S. Geological and Geographical Survey following the Civil War. The leading figures in this period of exploration were John Wesley Powell, Gore Karl Gilbert, and Clarence E. Dutton. Others of note during this time frame were Ferdinand V. Hayden, Lt. George N. Wheeler, and Archibald R. Marvine. As the west was being explored and the landforms analyzed, these individuals formulated several key ideas about geomorphology.

John Wesley Powell is undoubtedly the best known of these men. In his report on the Colorado River he developed the concept of base level. He also discussed the nature of erosional processes.[2] Powell recognized that although sea level was the permanent base level, temporary base levels could be created by outcrops of very hard rocks. In his paper on the Uinta Mountains, he presented a generic classification of landforms.[3] Because this system was based primarily upon geologic structure, it tended to be more of an index of landforms than a true classification system.

Gore Karl Gilbert served as an assistant to Powell during 1875-79 expeditions to Utah and later was one of the senior geologists in Washington, D.C., with the U.S. Geological Survey.

[2] John W. Powell, Exploration of the Colorado of the West and its Tributaries, (Washington, D.C.: Smithsonian Institute, 1875).

[3] John W. Powell, Report on the Geology of the Eastern Portion of the Uinta Mountains and Region of Country Adjacent Thereto, U.S. Geological and Geographical Survey, (Washington, D.C.: Government Printing Office, 1876).

Among his major contributions to geomorphic thought were the concept of a graded stream and his views concerning the formation of pediments. Gilbert's Report on the Geology of the Henry Mountains, in 1877 was the first treatment of the mechanics of fluvial processes by a geologist.[4] His 1890 monograph entitled the "History of Lake Bonneville" discussed the formation of pediments in arid areas.[5]

Clarence Dutton made contributions by creating an awareness of isostatic adjustments and descriptions of landforms. He also discussed the "Great Denudation," a period of extensive erosion which he felt created the Colorado Plateau. His writings also contained several references to the idea of parallel retreat of slopes.[6] This concept is based upon a belief that hillsides maintain their angle of slope and form as erosion occurs.

These men proposed ideas that laid a foundation for study and understanding of the effects of fluvial processes upon the landscape. It was this foundation which William Morris Davis used as a base for his concepts.

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[4]G.K. Gilbert, Report on the Geology of the Henry Mountains, U.S. Geographical and Geological Survey of the Rocky Mountain Region, (Washington, D.C.: Government Printing Office, 1877).

[5]G.K. Gilbert, "Contributions to the History of Lake Bonneville," in 2nd Annual Report of the U.S. Geological Survey, 1880-1881, (Washington, D.C.: Government Printing Office, 1882).

[6]William D. Thornbury, Principles of Geomorphology. (New York: John Wiley and Sons, 1969): 11.

WILLIAM MORRIS DAVIS

William Morris Davis is generally considered the founder of "Classical" American geomorphology. His 1899 article, "The Geographical Cycle," presents his primary thesis that all landforms are functions of structure, process, and stage or time (See Appendix, page 20). In discussing the three factors Davis states, "Structure is the foundation of all geographical classification in which the trio of controls is recognized."[7] He further states that a true and natural genetic classification of landforms should be an explanation of them, and that geographers have a need to understand the origin of forms. Using deductive logic, Davis describes the terms initial youth, maturity, and old age to represent stages in the evolution of landforms.

The Geographical Cycle, as envisioned by Davis, starts with the rapid uplifting of a plain and the beginning of fluvial erosion. Erosion of this initial stage soon produces the second stage, youth. This stage is characterized by low relief and poor drainage with broad flat water divides. As the erosional process continues, relief increases until the mature stage is reached. At this time, narrow ridges form water divides and very little flat terrain remains. Additional erosion leads to the old age stage in which relief is slight and low flat plains are dominant. The "almost

[7]William Morris Davis, "The Geographical Cycle," The Geographical Journal XIV (November, 1899): 482.

featureless" plain resulting from the Geographical Cycle was termed a peneplain by Davis. Among suggested examples of peneplains are the Rocky Mountain Peneplain in the Colorado Front Range and the Sherman Peneplain which forms the Gangplank area of Wyoming. The views expressed by Davis were adopted by many geographers, geologists, and geomorphologists because they were logical and easy to teach. The Geographical Cycle as presented by Davis has become known as the Geomorphic Cycle, Geologic Cycle, Cycle of Land-mass Denudation, and Cycle of Erosion in various geomorphology texts used in the United States.[8]

Although Davis' thoughts were quickly and soundly established in American geomorphology, there were several attacks upon the cyclic model. One early critic of Davis' work was Walter Penck. Penck and Davis corresponded regarding the cycle on several occasions prior to Penck's death in 1923. In 1924, Penck's monumental book, Die Morphologis Analyse, was published.[9] The German text was extremely difficult to interpret, and no English translation was completed until 1953. Penck believed that Davis' cycle was

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[8]See: Harvey Blatt, Gerald Middleton and Raymond Murray, Origin of Sedimentary Rocks (Englewood Cliffs, New Jersey: Prentice-Hall Inc., 1972), p. 20; Robert V. Ruhe, Geomorphology (Boston: Houghton Mifflin Co., 1975), p. 5; and Arthur N. Strahler, Physical Geography, 4th ed. (New York: John Wiley and Sons, Inc., 1975), p. 437.

[9]Walter Penck, Die Morphologische Analyse: Ein Kapitel der Physikalischen Geologie. (Stuttgart: Geographische Abhandlungerngen, 1924).

limited in its application, and that his own works were to be an extension of Davis' ideas. Penck considered the process of landscape formation to be the same in all climates with the type of crustal unit and crustal movement being responsible for differences in landscapes (See Appendix, page 22). Thus, he added crustal movement to Davis' structure, process, and time.

The two disagreed on several other points. Davis believed that the overall objective of geomorphic research was the determination of where a landscape fit into the Geographical Cycle. Penck thought that such research should serve to determine the history of a landscape.[10] Penck also stated that the Davisian idea of rapid uplift followed by a period of slower uplift was not normal and proposed his view that uplift began slowly then accelerated. Many Americans. Davis among them, claimed that Penck had expresaed the concept that valley walls undergo parallel retreat with erosion rather than that a gradual lowering of hilltops occurs. Parallel retreat of slopes does not fit into the Geographical Cycle because the resulting landscape would be a low plain with steep sharp ridges rather than the smoothe. peneplain.

The controversy over Davis' cyclic model continued through the 1930's. Several works of that decade indicated an interest in a numerical analysis of landforms and processes. For example,

[10] Martin Simons, "The Morphological Analysis of Landforms: A New Review of the Work of Walter Penck." Institute of British Geographers, Transactions and Papers. Pub #31, 1962.

in a 1932 article, R.E. Horton applied numerical analysis to stream length and width.[11] Papers of this nature reflect the then growing opposition to the deductive nature of the Davisian cycle. In defense of the cycle, Fenneman stated that, "The cycle itself is not a physical process but a philosophical conception."[12]

By the end of the 1930's, the prevailing thought in geomorphology was that Davis' ideas were valid. As Bloom states, "Besides, since experimentation in the processes of landscape evolution is so difficult, it was largely ignored."[13]

QUANTITATIVE REVOLUTION

During World War II there was a need for quantitative analysis of many landforms, particularly of beaches and coastlines. The use of aerial photography provided a rapid method of examining landforms and drainage systems to obtain such information. This led to the accumulation of large amounts of data which could be numerically analyzed. Requirements for these data initiated a shift in geomorphology away from purely descriptive research to the beginning of what Dury has termed the quantitative revolution.[14]

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[11] R.E. Horton, "Drainage Basin Characteristics," Transactions of the American Geophysical Union, XIII (1932): 350-361.

[12] Nevel N. Fenneman, "Cyclic and Non-Cyclic Aspects of Erosion." Bulletin of the Geological Society of America, XLVII (1937): 182.

[13] Arthur L. Bloom, The Surface of the Earth, (Englewood Cliffs, New Jersey: Prentice-Hall Co., 1969), p. 2.

[14] Dury, p. 27.

The quantitative revolution may be considered to have bee. formally initiated in 1945 with the publication of Horton's .sic paper, "Erosional Development of Streams and Their Drain-- Basins: Hydrophysical Approach to Quantitative Morphology."[15] (See Appendix, page 23). Horton indicated in this paper that when streams are arranged in a network hierarchy, many geometric factors such as stream number and stream length show definite relationships. He expressed those relationships as the Law of Stream Order, Law of Stream Numbers and the Bifurcation Ratio. In discussing Horton's contribution, Dury states, "He made analysis of drainage networks and drainage geometry numerical and objective, as against subjective, which it had previously been."[16] As a result of Horton's presentation, analysis of drainage systems was revolutionized.

Many geomorphologists adopted and modified the concepts proposed by Horton. One of the leaders of this movement, along with his contemporaries at Columbia University, was A.N. Strahler. He used stream basin ordering to identify basins of comparable characteristics. Research in the geometry of such basins led to the formulation and application of such indicies as texture ratios, relief ratio, and the constant of channel maintenance.[17] (See

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[15] R.E. Horton, "Erosional Development of Streams and Their Drainage Basins: Hydrophysical Approach to Quantitative Morphology." Bulletin of the Geological Society of America, LVI (1945): 275-370.

[16] Dury, p. 28.

[17] Arthur N. Strahler, "Quantitative Analysis of Watershed Geomorphology," Transactions, American Geophysical Union, XXXVIII (December, 1957): 913-920.

Appendix, page 25). He devised the hypsometric integral to determine the amount of an original landscape which had been removed by erosion. Strahler felt that, "Formulation of mathematical models, both by rational deductive and empirical analysis of observable data, to relate energy, mass, and time is the ultimate goal of the dynamic approach."[18]

In addition to the study of landforms, interest in stream characteristics and morphology was renewed following World War II. Gilbert had written a paper in 1914 in which he concluded that stream capacity was dependent upon discharge, stream gradient, and the nature of the stream load. This served as a background for the 1956 study of ephemeral streams by Leopold and Miller. Later, fluvial geomorphologists reexamined the ideas expressed in these works in an attempt to determine cause and effect relationships. Schumm, while examing the type sediments along stream banks, was able to correlate the sediments to the nature of the stream cross section. This correlation indicated that a cause and effect relationship does exist between two factors.[19] The relationship of this and similar research to other fields of geomorphology is quite strong. Morisawa expressed the view that, "To understand

[18]Arthur N. Strahler, "Dynamic Basis of Geomorphology," Bulletin of the Geological Society of America 63 (September, 1952): 923.

[19]Stanley Schumm, The Shape of Alluvial Channels in Relation to Sediment Types. U.S. Geological Survey Professional Paper 352B. (Washington, D.C.: Government Printing Office, 1960).

fully and interpret landforms a knowledge of the physical principles by which a river operates is necessary."[20]

Research along the lines mentioned indicate a shift in the overall objective of geomorphology. Geomorphology was no longer used as a means to deduce earth history but rather earth processes became the focus of research.[21]

Time in Landform Analysis

Several authors have attached the time variable inherent to the Geographical Cycle. J.T. Hack is a major proponent of a time independent view of landforms. Hack, in his landmark paper of 1960, stated that in his work regarding the Central Appalachians, ". . . a conscious effort was made to abandon the cyclic theory as an explanation for landforms,"[22] (See Appendix, page 26). He also expressed the view that "maturely dissected" topography as described by Davis, tended to be dominant throughout the world and should be considered the end result of erosion. As an alternative to the time bound cyclic concept, Hack proposed the principle of Dynamic

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[20]Marie Morisawa, Streams: Their Dynamics and Morphology. (New York: McGraw-Hill Co., 1968), P. .

[21]Ronald C. Flemal, "The Attack on the Davisian System of Geomorphology: A Synopsis," Journal of Geological Education, XIX (1971): 4.

[22]John T. Hack, "Interpretation of Erosional Topography in Humid Temperate Regions," American Journal of Science CLXXXVIII-A (1960), p. 81.

Equilibrium which he believed could be traced to the works of Gilbert, Davis, and Strahler. Hack stated that,

> When the topography is in equilibrium and erosional energy remains the same all elements of the topography are down-wasting at the same rate. Differences in relief and form may be explained in terms of spatial relations rather in terms of an evolutionary development through time.[23]

If the balance inferred in this concept is upset the topography will change until another state of balance is achieved. Hack also felt that:

> The analysis of topography in terms of spatial or time-independent relations provides a workable basis for the interpretation of landscape. This kind of analysis is uniformitarian in its approach, for it attempts to explain landscapes in terms of processes and rates that are in existence today and therefore observable.[24]

Chorley expanded the dynamic and time independence nature of Strahler and Hack's work by relating fluvial geomorphology to the general systems theory (See Appendix, page 27). Strahler had discussed the two forms of systems, closed and open, in his 1952 paper. A closed system is one in which there are boundaries which no energy or materials may cross. Thus, a closed system begins with a limited amount of energy. Chorley classified Davis' cyclic model as a closed system which by its nature is, ". . . eminently susceptible to study on a time, or historical basis."[25] Open

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[23] Ibid.

[24] Ibid., p. 87.

[25] Richard J. Chorley, Geomorphology and General Systems Theory. U.S. Geological Survey Professional Paper 500-B. (Washington, D.C.: Government Printing Office, 1962), p. B3.

systems on the other hand are maintained by export and input of energy and materials. Dynamic equilibrium occurs in an open system in which landscape features may be considered time independent.

Schumm and Lichty addressed the problem of time dependent and time independent theories in 1965 (See Appendix, page 28). They point out that Hack had eliminated time from his consideration and then allowed it to reenter his definition of dynamic equilibrium. They believe dynamic equilibrium and the cyclic concept to be compatible when differences in the time span and space were considered; therefore, "The steady state concept can fit into the cycle of erosion when it is realized that steady states can be maintained only for fractions of the total time involved."[26]

Peneplains and Pedeplains

Another of the major areas of discussion in fluvial geomorphology concerning the Geographical Cycle is the idea of peneplanation. Parallel retreat of slopes, which originally had been inferred by Dutton and also attributed to Walter Penck, results in a different landscape than the peneplain of the Davisian cycle. L.C. King has been one of the leading proponents of this concept. His work in the semi-arid portions of Africa also led to his conclusions that the peneplain as described by Davis did not

[26]Stanley A. Schumm and R.W. Lichty. "Time, Space, and Causality in Geomorphology," American Journal of Science CCLXIII (February, 1965): 119.

exist.[27] (See Appendix, page 30). King believes that the final stages in the geographical cycle is the pediplain. Pediplains are created by the coalescing of pediments which are formed as cliffs undergo parallel retreat. The surface of a pediplain has a concave slope in comparison to the convex slope associated with peneplains.[28] Investigation in several locations by Schumm has supported the concept of parallel retreat of slopes.[29] Schumm also conducted an extensive review of the geomorphic literature which together with his investigations, led to his belief that both parallel retreat and the declining retreat of the Davisian peneplanation occurred in nature. The ". . . topography, climate, geology, soil and erosional processes could combine in varying combinations to give either."[30] (See Appendix, page 31). This concept has been widely accepted in fluvial geomorphology.[31]

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[27] L.C. King, "Canons of Landscape Evolution," Bulletin of the Geological Society of America, LXIV (1963): 721-751.

[28] E.H. Brown, "Peneplain," in The Encyclopedia of Geomorphology, ed. Rhodes W. Fairbridge (New York: Reinhold Book Corp., 1968), p. 821.

[29] Stanley A. Schumm, "Evolution of Drainage Systems and Slopes in Badlands at Penth Ambay, New Jersey," Bulletin of the Geological Society of America, LXVII (1956): 597-646.

[30] Flema , 10.

[31] Karl W. Butzer, Geomorphology From the Earth, (New York: Harper and Row, 1976), p. 111.

PRESENT STATUS

One significant aspect of the general system and specifically of the open systems approach to geomorphology has been the idea that a landscape may have several origins. This approach is directly opposed to the Davisian concept of a single origin. Hack discussed the problem of "relict landforms" and felt that, "If. . . sudden diastrophic movements occur, relict landforms may be present in the topography until a new steady state is achieved."[32] This has become one area of present day discussion and analysis. A relict landform is defined as being, "situated within an environment where it apparently could not have formed."[33] Relict forms include the Sand Hills of Nebraska, a similar form in northern Nigeria, and deranged drainage patterns. Existence of these forms indicates an "initial stage of disequilibrium."[34]

Today fluvial geomorphology encompasses three main views: the old "classical" geomorphology of Davis, the dynamic equilibrium of Hack and Strahler, and the pediplanation cycle of King. Because of its cyclic nature, the pediplanation theory has encountered much of the same opposition as the Geographical Cycle.

This model depicts the development of thought related to fluvial geomorphology.

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[32] Hack, p. 86.

[33] Garner, p. 18.

[34] Ibid., p. 27.

A crude model of the development of thought related to fluvial geomorphology is shown in Figure 1.

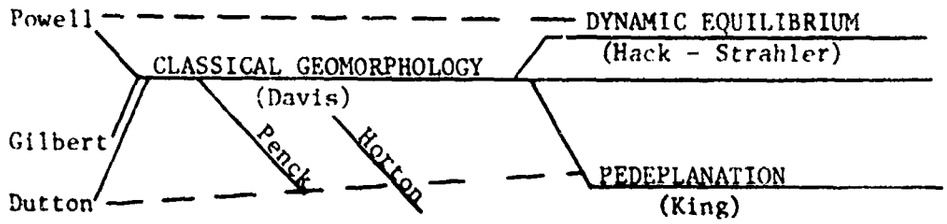

Figure 1

Classical and dynamic equilibrium have in effect been combined. The great majority of geomorphology courses taught in 1971 used texts which could be considered "classical" in approach with additional instruction in quantitative aspects.[35] This is in keeping with Strahler's point that both types of instruction are important in geography and that the "explanatory-descriptive" forms of instruction are best at the introductory level. He also states that quantitative methodology is of greater significance at the advanced level of research and study.[36]

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[35]Robert V. Ruhe, Geomorphology: Geomorphic Procures and Surficial Geology. (Boston, Mass: Houghton Mifflin Co., 1975), p. 5.

[36]Arthur N. Strahler, "Empirical and Explanatory Methods in Physical Geography." Professional Geographer, VI (1954), p. 5.

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APPENDIX

William Morris Davis. "The Geographic Cycle." The Geographical Journal XIV (5). Nov. 1899. pp. 481-504.

This article founded the "Davisian" school of geomorphology and contains some concepts which were unique or new at the time. It draws on several other sources such as Powell and Gilbert. Davis states that all forms of land were functions of three variables: structure, process, and time. Initially structure is determined by the forces of deformation and uplift. Processes of erosion begin to work on the structure soon after the structure is created. The change in form is not done immediately and time, thus, is the third factor. "Structure is the foundation of all geographical classifications. . . ."

Davis states that a true and natural genetic classification of geographic forms would also be an explanation of them and the geographer has a need to understand the origin of the forms he sees to describe them accurately. In this context Davis presents the terms youth, maturity, and old age. Davis does not feel that uplift or deformation occurrs so rapidly that erosion does not occur during the uplift, rather that erosion begins during the uplift. In a discussion of graded rivers, Davis states that when an equilibrium is reached between the ability to do work and the work to be done, the river is at grade. In areas of homogenous landmass, graded conditions occur initially at the mouth and then move

upstream. Old age is attained when the hilltops and hillsides are at grade. The landscape is then a "succession of gently rolling swells alternating with shallow valleys." As the relief is reduced an "almost featureless plain (a peneplain)" is formed.

Martin Simons. "The Morphological Analysis of Landforms: A New Review of the Work of Walter Penck." Institute of British Geographers, Transactions and Papers. Pub #31. 1962.

The purpose of this article is to point out several errors which have been made in an analysis of Penck's work. W.M. Davis credits Penck with the view that convex slopes are formed during periods of accelerated upheaval with concave slopes forming during periods of decreasing upheaval. Davis also credits Penck with statements supporting the parallel retreat of slopes. According to Simons Penck does not hold these views and believes that concave and convex slopes are the result of continuous accelerating uplift. Penck considers the process of landscape formation to be the same in all climates with the type of crustal unit and crustal movement responsible for differences.

Penck recognizes two types of motion, folding and subsidence. Based on these motions he establishes three types of crustal units: regions of "great folding" and doming, regions of doming, and regions of stability. The Puna de Atacama of South America is cited as an area of great folding while the Black Forest is given as an example of areas of domes with no folding. Penck feels that a third landform association, that of inselbergs, is found to extend "over very vast areas of the earth's crust" and is not distinctive of a climate type but rather of continental masses.

Robert E. Horton. "Erosional Development of Streams and Their Drainage Basins: Hydrophysical Approach to Quantitative Morphology." Bulletin Geological Society of America. LVI 1945, pp. 275-370.

In this paper, Horton provides material which he hopes will fill a lack of sufficient quantitative base in geomorphology. He proposes that the reverse of a stream ordering system used in Europe be employed in geomorphic research. Horton discusses the drainage network stating that neither the drainage pattern nor the drainage density provides "an adequate characterization of the stream system." He feels that stream density and stream frequency expressed as the total number of streams in a basin divided by the area of the basin, can be united into the "composition of a drainage net." Horton defines the infiltration capacity of soil, basing his definition upon a maximum rate of absorption of rain, relation between surface detention and the rate of runoff. The infiltration capacity is governed by soil texture, structure, vegetation, biological factors, moisture content, and condition of the surface. The infiltration capacity decreases during a rain until it reaches a lower constant value. The difference between rain intensity and infiltration capacity is largely runoff. Horton, in a segment of his paper discussing surface erosion and sheet flow, presents many laws governing the processes involved.

Horton discusses at length the development of stream systems and compares the hydrophysical process to the Davisian Cycle.

Horton feels the two are compatable but that one of the major problems is the usage of "young" and "mature" as terms to describe landscapes. Horton feels that an area can be mature even though its surface appears youthful.

Arthur N. Strahler. "Quantitative Analysis of Watershed Geomorphology." Transactions of the American Geophysical Union. XXXVIII (6), 1957, pp. 913-920.

This paper presents several concepts in quantitative analysis of geomorphology. Strahler discusses such innovations as dimensional analysis of stream basins. He presents the idea of stream order with the understanding that its usefulness would depend upon its being directly proportional to watershed dimension. The area of the drainage basin is indicated to be a property of the square of the length and found to increase exponentially with stream order. By plotting the logarithm of the basin area as a function of the logarithm of the total stream length, an anti-log, which is the constant of channel maintenance, is acquired. Discussions of mean slope curve, slope maps, and relief ratio lead to a presentation of the hypsometric analysis which Strahler applies to numerous small basins. The hypsometric curve gives a quantitative measure of youth, maturity and old age, or as Strahler prefers, the monadnock phase.

John T. Hack. "Interpretation of Erosional Topography in Humid Temperate Regions." 1960. American Journal of Science. Vol. CCLVIII (Bradley volume), pp. 80-97.

Hack states that the dynamic equilibrium theory can be traced back to Gilbert. Hack attacks the geographic cycle as unrealistic due to the concept of graded streams and old age landforms. Gilbert's concept of lateral planation differs from Davis' ideas in that pediments are created by lateral shifting of streams and the lateral shifting was due to the transportation of a bed load which was more resistant than the rock the stream is passing through. If the bed load is less resistant than the rock, lateral planation does not occur. This concept involves a dynamic equilibrium. The concept of graded streams as presented by Davis and Mackin is dispensed of in favor of an equilibrium balance of seven variables achieved almost immediately in the development of a valley. Hack uses the lack of old age landforms as described by Davis to arrive at the conclusion that "maturely dissected" erosional surfaces may be the goal of erosion.

The concept of dynamic equilibrium infers a state of balance between opposing forces with energy constantly entering and leaving the system independently of time. Every slope and channel in a system is adjusted to each other and downwasting then occurs at the same rate in all areas. Topographical forms can be analyzed using the concept of a balance between erosional processes and the resistance of rocks as they are uplifted or tilted by diastrophism.

Richard J. Chorley. Geomorphology and General Systems Theory. U.S. Geologic Survey Professional Paper 500-B 1962.

There are two distinct systems theories which may be employed in observation of the physical phenomena of the earth, the open system and the closed system. Closed systems have borders across which no materials or energy may pass. Closed systems have been used for most geographic studies. There is a leveling down of features within this type of system, and the Davisian geographical cycle falls in this category. The concept of a graded stream involves an equilibrium which is impossible within a closed system and therefore is hard to include within the geographical cycle.

Open systems offer many contrasts to the closed systems and may include closed systems as special cases. The open system shifts emphasis onto both form and process. It also allows for the possibility that the same end result may be achieved by differing processes. The open system allows a "more liberal view of changes of form with time," and allows broader ideas concerning the aim and methods of geomorphology. The entire landscape is considered rather than just certain elements of the landscape as under the closed system.

S.A. Schumm and R.W. Lichty. "Time, Space, and Causality in Geomorphology." American Journal of Science. CCLXIII February 1965, pp. 110-119.

The idea of time in Geomorphology has been the topic of many analyses. In his paper, "Interpretation of Erosional Topography in Humid Temperate Regions," Hack excluded time from the dynamic equilibrium but then allowed it to enter the system by stating that erosional energy changed with time (see page 27). The authors feel that time can not be excluded. In discussing the cycle of erosion three lengths of time are presented: cyclic, graded, and steady. Cyclic time is defined as the life span of an erosional cycle. A fluvial system during this time span is an open system with time, geology, initial relief, and climate as independent variables. The graded time span is a short segment of cyclic time when dynamic equilibrium exists. Here there is a series of changes approaching a steady state. Dynamic equilibrium does not apply to the entire drainage system and time has been eliminated as an independent variable. A segment of graded time called steady time denotes a truly steady state in the dynamic equilibrium. The hydraulic steady flow occurs for only a short period of time and only for one segment of the drainage basin. Thus, depending on the time span involved, time may be extremely important, an independent variable, or of relatively little significance.

In river channel morphology and hydrology time also may be divided into three spans: geologic, modern, and present. In

geologic time, from 1,000,000 years ago to the present, time, geology, and climate are independent variables. In modern time or the last 1000 years the number of independent variables increases. In the present time a reversal of cause and effect may occur and brief modifications are present. A shift from dependence to independence among the variables in a system occurs with a decrease in the time element.

The conclusions of this study are that, "The distinction of cause and effect among geomorphic variables varies with the size of landscape and with time."

L.C. King. "Canons of Landscape Evolution." Bulletin of the Geological Society of America. LXIV (July 1963), 721-751.

The author states that four elements occur in a hillside slope: waxing slope, free face slope, debris slope and waning slope or pediment. If the free face and debris slopes are actively eroding the hillside retreats parallel to itself. When these two slopes are inactive, the waxing slope extends down to the waning slope and degenerate slopes occur. Erosion of the free face and debris slopes is primarily the result of rill wash forming gully heads. According to Dr. King, "Davis' old deduction of continuous lowering of hillside gradiants, a feature also of Strahler's 'Equilibrium Theory' is incorrect and never existed." Rather, landscapes are the result of the parallel retreat of escarpments. The ultimate cyclic landform is the pediplain which is composed of numerous broad, concave pediment or pediment-like surfaces. Pediments are rock floors which are normally covered by debris and begin as the waning slopes of hillsides. The pediplain is multi-concave upward. Davis' peneplain "does not exist in nature and is an imaginary landform."

Stanley A. Schumm. "Evolution of Drainage Systems and Slopes in Badlands at Perth Amboy, New Jersey." Bulletin of the Geologic Society of America. LXVII (I) 1956, pp. 597-646.

Schumm's article is based on an in-depth analysis of the development of stream networks in a clay-sand fill area in New Jersey. He also compares the badlands topography and drainage system which evolve with systems of a similar nature in other areas. The streams of the area are found to conform with laws formulated by Horton. Schumm proposes a fourth law of drainage composition, "The mean drainage basin areas of streams of each order tend to approximate closely a direct geometric series in which the first term is the mean area of the first order streams." In a like manner a fifth law is proposed. "The relationship between mean drainage-basin areas of each order and mean channel lengths of each order of any drainage network is a linear function where slope (regression coefficient) is equivalent to the area in square feet necessary on the average for the maintenance of a 1 foot of drainage channel." Based on the evidence collected, parallel retreat of slopes may be dominant in the study area.